Journal of Hydro-environment Research 14 (2017) 61–75

Contents lists available at ScienceDirect

Journal of Hydro-environment Research

journal homepage: www.elsevier.com/locate/JHER

Research papers

The effects of a typhoon-induced oceanic cold wake on typhoon intensity and typhoon-induced ocean waves

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ARTICLE INFO

Article history:
Received 13 March 2015
Revised 30 May 2016
Accepted 10 June 2016
Available online 21 September 2016

Keywords:
Oceanic cold wake
Typhoon
Bolaven
Tembin
Typhoon-induced wave

ABSTRACT

In August 2012, binary typhoon activity occurred near the Korean Peninsula (KP) involving typhoons Bolaven (1215) and Tembin (1214). Typhoon Bolaven was recorded as the strongest typhoon to pass over the Yellow Sea since 2000. Typhoon Tembin remained in the southwestern Sea of Taiwan for nine days before moving toward the KP along the track of Typhoon Bolaven. The purpose of this study is to investigate the effects of the oceanic cold wake of Typhoon Bolaven on the intensity, track, and movement speed of Typhoon Tembin. Moreover, we examine the impacts of surface temperature cooling caused by the passing of a previous typhoon on the intensity of a later typhoon and typhoon-induced waves. We use the Advanced Research version of the Weather Research and Forecasting (WRF-ARW) model at grid spacings of 20 km and 4 km in addition to the open ocean wave prediction model (WAM) and the Wavewatch III model (WW3). A large surface temperature cooling caused by vertical mixing and upwelling induced by the previous typhoon resulted in a significant decrease in intensity and change in the movement speed of the next typhoon. These results demonstrate that the intensity of the succeeding KP-landfall typhoon is highly sensitive to the previous typhoon's track and resultant upper-ocean thermal structures.

1. Introduction

The western North Pacific Ocean has the highest concentration of tropical cyclones (TCs), known in this region called typhoons. The average TC occurrence over the western North Pacific is approximately 26 per year, with maximum cyclone activity in August and high seasonal variation (McBride, 1981). Forecasting a TC track is one of the most difficult tasks in weather prediction over the western North Pacific because of the lack of conventional data over the ocean. In this region, an anomalous track of a typhoon is often associated with the coexistence of two or more TCs. Observational evidence (Brand, 1970) has shown that two or more TCs can interact when they exist concurrently with distance less than approximately 1450 km. These situations occur more frequently in the western and eastern North Pacific (Ramage, 1972; Lander and Holland, 1993) with a maximum frequency of 7.4 occurrences per year (Hsiao, 2000). Interactions between multiple TCs may induce abrupt changes in tracks, intensity, and moving speed.

The relatively thin layer of warm ocean water, an energy source of TCs, lies above deep, cold water. The strong winds and large ocean waves induced by TCs in addition to upwelling, advection, and air–sea fluxes cool the upper layer by mixing the colder water with the warmer oceanic layer in a process known as the cold wake of a TC passage. Sakaida et al. (1998) reported 9 °C maximum cooling of the sea surface temperature (SST) after the passage of a typhoon. Cold wakes reduce the available energy and limit TC intensity. The effect of a cold wake persists for a few days, but a residual cold subsurface layer persisted for 10–30 days (D'Asaro et al., 2014). Significant anomalous tracks were observed in August 2012 when Typhoon Bolaven (1215), a super typhoon, and Typhoon Tembin (1214) were evaluated at short distances. Typhoon Tembin remained in the southwestern Sea of Taiwan for nine days before moving toward the Korean Peninsula (KP) along the track of Typhoon Bolaven. The cold wake induced by Typhoon Bolaven lasted for five days and affected the intensity, track, and movement speed of Typhoon Tembin. Recent studies have shown that the weakening of typhoon intensity results mainly from typhoon-induced SST cooling within the typhoon. Although previous studies generally agree that typhoon-induced SST cooling can have a significant impact on typhoon intensity, research on the

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http://dx.doi.org/10.1016/j.jher.2016.06.002
1570-6443/

Table 1
Location of observational wave stations.

Station	Location	WMO code	Longitude (°*E*)	Latitude (°N)
Deokjeokdo	YS	22101	126.01889	37.23611
Chilbaldo	YS	22102	125.77694	34.79333
Geomundo	SS	22103	127.50139	34.00139
Geojedo	SS	22104	128.90000	34.76667
Marado	SS	22107	126.03333	33.08333
Oeyeondo	YS	22108	125.75000	36.25000
Shinan	YS	22183	126.24167	34.73333
Chujado	SS	22184	126.14111	33.79361
Anmado	YS	–	126.09086	35.39661
Pyosun	SS	–	126.88147	33.31167
Biyangdo	SS	–	126.20528	33.40717
Jungrui	SS	–	126.32244	33.79753

Note: WMO: World Meteorological Organization; YS: Yellow Sea; SS: South Sea.

impact of a preceding typhoon-induced SST cooling on the intensity of a succeeding typhoon is rare.

The purpose of the present study is to investigate preceding typhoon-induced SST cooling on the intensity of a succeeding typhoon and the resultant wave height and storm surge. This relation between the two typhoons is regarded as a case of binary interaction. Based on the Advanced Research version of the Weather Research and Forecasting (WRF-ARW) model, sensitivity experiments are conducted in the present study to determine the effects of the oceanic cold wake produced by Typhoon Bolaven on the intensity, track, and movement speed of Typhoon Tembin. Section 2 introduces the data, model descriptions, and experiment details, and Section 3 introduces the details of the case study. Section 4 presents the results of the numerical experiments using meteorological, wave, and storm surge models, and a discussion and conclusions are provided in Sections 5 and 6, respectively.

2. Data and model description

2.1. Data

The Terra/Moderate Resolution Imaging Spectroradiometer (MODIS) visible image data were employed in the present study, as were the available buoy data recorded along the southwestern coast of Korea (Table 1), which were quality-checked and archived by the Korea Meteorological Administration (KMA). Data were unavailable from buoys damaged by Typhoon Bolaven. In addition, the temporary wave observation stations established by the Korea Institute of Ocean Science and Technology (KIOST) along the south coast of Korea were employed to assess wave height (Table 1).

The performances of mesoscale models depend on the quality, reliability, and representativeness of initial values and lateral boundary conditions. For numerical simulation of the meteorological model, the real-time analysis field obtained from the global final analysis (FNL) run by the National Centers for Environmental Prediction (NCEP), with 1° resolution, was taken as the initial and 6-h forecast files and as initial and lateral boundary conditions. The FNL analyses were obtained by NCEP's Global Data Assimilation System (GDAS; Kanamitsu, 1989); this final run includes all the late-arriving conventional and satellite data. The analyses fields in 6-h intervals serve as initial and lateral boundary conditions to the model. NCEP's daily global SST analysis (RTG_SST_HR) is used in the meteorological model from which we interpolated 6-h SST data.

2.2. Model description and experiment details

The Korea Operational Oceanographic System (KOOS) is a research project funded by the Ministry of Oceans and Fisheries (MOF), Korea, to develop an integrated operational oceanographic system that will provide nowcasts and forecasts of ocean information around the KP. In this study, numerical experiments were conducted by using the numerical weather forecasting system of KOOS; detailed descriptions are given in this subsection.

Table 2
Physical parameterizations used in the experiments determined by using the Weather Research and Forecasting (WRF) model.

Processes	Scheme	Reference
PBL scheme	YSU PBL scheme	Hong et al. (2006)
Surface layer physics	Noah LSM	Mitchell (2005)
Cumulus convection	Kain-Fritsch	Kain and Fritsch (1993)
Radiation	Dudhia short-wave and RRTM long-wave radiation scheme	Dudhia (1989)
Microphysics	Five-class microphysics scheme	Lin et al. (1983)

Note: PBL: planetary boundary layer; YSU: Yonsei University; LSM: land surface model; RRTM: rapid radiative transfer model.

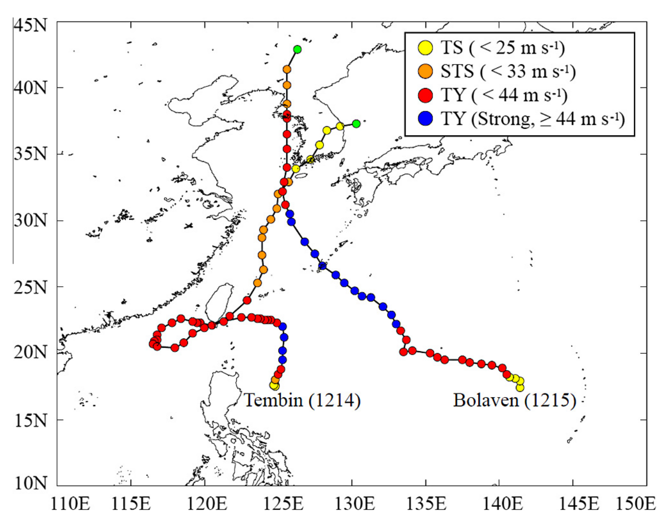

Fig. 1. KMA-analyzed tracks of Tembin (1214) and Bolaven (1215) over the western North Pacific.

First, the WRF model (Skamarock et al., 2005) version 3.4-7 was used to obtain a comprehensive three-dimensional structure of the TC. The WRF model is an area-limited, fully compressible, non-hydrostatic numerical model formulated in Arakawa C-grid staggering horizontal grid and a terrain-following hydrostatic pressure